Tanta University
Faculty of engineering
Electrical Power and Machines engineering department
Principles of Energy Conversion Course

Sheet (2) …… D.C. Motors

1) A 4 pole, lap wound, D.C. motor has 540 conductors. Its speed is found to be 1000 r.p.m. when it is made to run light. The flux per pole is 25 mWb. It is connected to 230 V D.C. supply. The armature resistance is 0.8 Ω. Calculate:
   i) Induced e.m.f. ii) Armature current iii) Stray losses iv) Lost torque

P51

2) A d.c. shunt motor runs at a speed of 1000 r.p.m. on no load taking a current of 6 A from the supply, when connected to 220 V d.c. supply. Its full load current is 50 A. Calculate its speed on full-load. Assume R_a=0.3 Ω and R_{sh}=110 Ω.

P62

3) A d.c. series motor is running with a speed of 800 r.p.m. while taking a current of 20 A from the supply. If the load is changed such that the current drawn by the motor is increased to 50 A, calculate the speed of the motor on new load. The armature and series field winding resistances are 0.2 Ω and 0.3 Ω respectively. Assume the flux produced is proportional to the current. Assume supply voltage as 250 V.

P63

4) A 250 V d.c. shunt motor has a shunt field resistance of 200 Ω and an armature resistance of 0.3 Ω. For a given load, motor runs at 1500 r.p.m. drawing a current of 22 A from the supply. If a resistance of 150 Ω is added in series with the field winding, find the new armature current and the speed. Assume load torque constant and magnetization curve to be linear.

P75

5) A d.c. series motor runs at 500 r.p.m. on 220 V supply drawing a current of 50 A. the total resistance of the machine is 0.15 Ω, calculate the value of the extra resistance to be connected in series with the motor circuit that will reduce the speed to 300 r.p.m. The load torque being half of the previous value. Assume flux proportional to the current.

P80

6) A 500 V d.c. shunt motor runs at its normal speed of 250 r.p.m. when the armature current is 200 A. The armature resistance is 0.12 Ω. Calculate the speed when a resistance is inserted in the field reducing the shunt field current to 80% of the normal value and the armature current is 100 A.

P99

Best wishes
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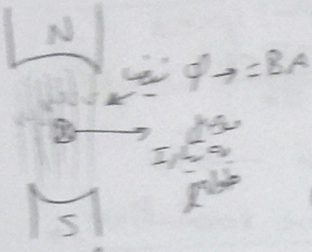
①

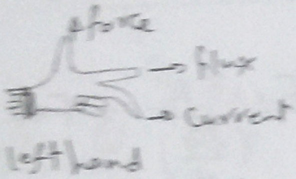
Electrical Motor

فكرة العمل: عند وضع موصل يمر به تيار كهربي في مجال مغناطيسي يؤثر هذا المجال بقوة تؤدي إلى تحريكه هذه القوة يعبر عنها كالتالي:



$F = B l I$ (N)

- B → flux density
- l → length of conductor
- I → Current passing Conductor

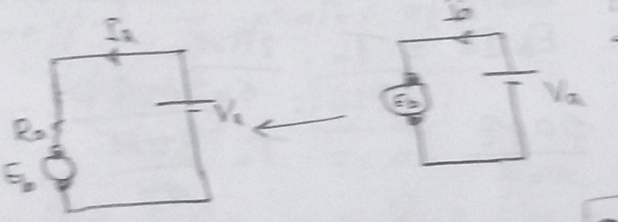


← يتم تحديد إتجاه هذه ال force بواسطة قاعدة اليد اليسرى
أما في المولد يتم تحديد ال Emf " " اليمنى

← لعكس إتجاه دوران الموتور يتم عكس أطراف المجال أو تغيير إتجاه التيار المار في الموصل.

← يتم تمثيل ال back Emf في الموتور بالعلاقة الآتية $E_b = \frac{\phi P N Z}{60A}$ مثل المولد ويكون هنا back لأنها تتولد وتكون في إتجاه عكس الاتجاه المسبب لتكوينها حسب قاعدة لنز.

← تمثيل معادلة الموتور:



$\therefore V_a = I_a R_a + E_b + V_{brush}$ $\therefore$ $\boxed{I_a = \frac{V_a - E_b}{R_a}}$

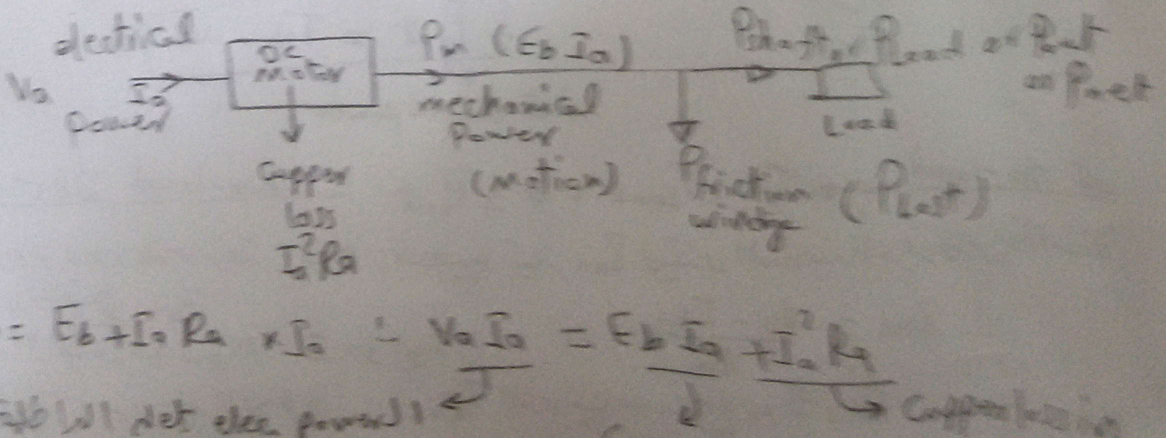
وتختلف المعادلة في دكريشن على حسب نوع الموتور

← أنواع ال DC Motor:

- → Separately excited
- → shunt
- → series
- → Compound → short shunt / → long "

مع كتابة معادلات كل نوع لتوضيح الرسم

← Motor Power Equation:



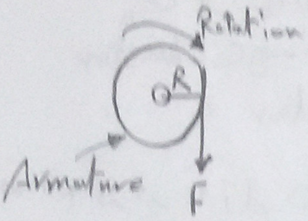
$V_a = E_b + I_a R_a \quad \times I_a \quad \therefore \underbrace{V_a I_a}_{\text{net elec. power الداخلة}} = \underbrace{E_b I_a}_{\text{Gross mechanical Power } (P_m)} + \underbrace{I_a^2 R_a}_{\text{Copper loss in Armature}}$

i/p

②

so P_m = Power i/p − Arm. copper loss

← معادلة العزم في الموتور : Torque Equ.



if the motor rotate with N (rpm) speed

so angular speed $\omega = \frac{2\pi N}{60}$ rad/sec.

work done in one revolution → W

$W = F \times$ distance in one revolution → محيط دائرة $2\pi R$

$W = F \times 2\pi R$

القدرة المتولدة : Power developed or gross mech. Power

$$P_d = \frac{W}{t} = \frac{F \times 2\pi R}{\text{زمن لفة واحدة}} = \frac{F \times 2\pi R}{\left(\frac{60}{N}\right)} = F \times R \times \left(\frac{2\pi N}{60}\right)$$

where $\omega = \frac{2\pi N}{60}$, $T = F \times R$ القوة × الذراع

$\therefore P_a = T_a \cdot \omega$

P_a → gross mech.

T_a → gross Torque or Arm. Torque or developed Torque

$$\therefore E_b I_a = T_a \cdot \frac{2\pi N}{60}$$

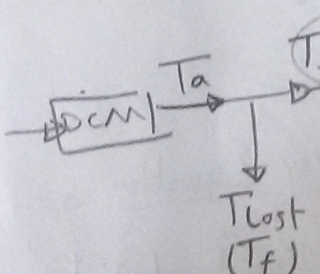
$$\frac{\phi P N Z}{60 A} I_a = T_a \frac{2\pi N}{60}$$

$$\therefore T_a = \frac{1}{2\pi} \cdot I_a \cdot \phi \cdot \frac{PZ}{A}$$

Torque Equation of D.C motor ←

$$\boxed{\therefore T_a = 0.159\, \phi\, I_a \frac{PZ}{A}} \quad (N.m)$$

← أنواع العزوم في الموتور :



$T_{sh} = T_{Load}$ → Called useful Torque

$\therefore T_a = T_f + T_{sh}$

$$\boxed{\therefore P_{out} = T_{sh} \cdot \omega}$$

P_{out} → Net output power

← العزوم عند no-load :

at No-load → $T_{sh} = T_{Load} = 0 = P_{out}$

ولكن الموتور يدور بسرعة N_o ويسحب تيار I_{ao} ليغطي المفاقيد الموجودة في الآلة فقط

وبالتالي تتولد E_{bo}

$$\therefore I_{ao} = \frac{V_a - E_{bo}}{R_a}$$

وبما أن الـ ϕ موجود والـ I_a موجود

∴ هيتولد عزم عند اللاحمل T_{ao} الذي يتناسب مع $\propto I_{ao}\phi$

(3)

$\therefore T_{ao} \propto \phi I_{ao}$

$\because T_a = T_f + T_{sh}$ $\therefore \boxed{T_{ao} = T_f}$

$\underbrace{T_{sh}}_{\to 0}$

∴ العزم الناتج عند اللاحمل هو العزم المفقود من الـ shaft

So Power developed $\boxed{E_{bo} I_{ao}}$ = friction, windage, iron losses

called stray losses

$$\therefore T_{ao} = T_f = \frac{P_{ao}}{\omega_o} = \frac{E_{bo} I_{ao}}{\left(\frac{2\pi N_o}{60}\right)} \quad N.m$$

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problem (1) $P = 4$, $A = P = 4$, $Z = 540$, $N = 1000$ rpm (when run light)

$\phi = 25 \times 10^{-3}$ wb, $V_a = 230$ V, $R_a = 0.8\,\Omega$ N_o

Req. E_{bo}, I_{ao}, P_{stray}, T_f

الحل

$N_o \longrightarrow 1000$ rpm $\because$ Motor operate at no-load

$$\therefore E_{bo} = \frac{\phi P N_o Z}{60 A} = \boxed{225\,V}$$

$$\because V_a = E_b + I_a R_a \longrightarrow V_a = E_{bo} + I_{ao} R_a$$

$$\therefore I_{ao} = \frac{230 - 225}{0.8} = \boxed{6.25\,A}$$

$$P_{stray} = E_{bo} I_{ao} = \boxed{1406.25\,W}$$

$$T_f = \frac{P_{stray}}{\omega_o} = \frac{P_{ao}}{\omega_o} = \frac{1406.25}{\left(\frac{2\pi \times 1000}{60}\right)} = \boxed{13.428\,N.m}$$

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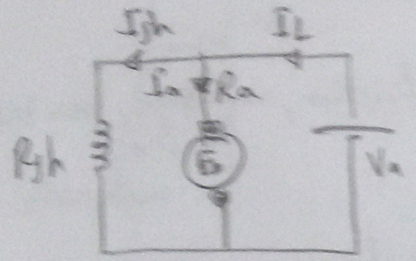
(4)

problem (2) $N_o = 1000\,rpm$, $I_{Lo} = 6A$, $V_a = 220V$, $I_{f.L} = 50A$

$N_{f.L} = ?$, $R_a = 0.3\,\Omega$, $R_{sh} = 110\,\Omega$



الحل

→ at no-load $I_{Lo} = 6A$

$\therefore \underset{6}{I_{Lo}} = I_{ao} + I_{sh}$, $I_{sh} = \dfrac{220}{110} = 2\,A$

$\therefore \boxed{I_{ao} = 6 - 2 = 4\,A}$

$\therefore V_a = E_{bo} + I_{ao} R_a$

$\therefore \boxed{E_{bo} = 218.8\,V}$

→ at full load $I_{sh} \longrightarrow$ const.

$I_{Lf.L} = 50 = I_{af.L} + I_{sh}$

$\therefore I_{af.L} = 50 - 2 = \boxed{48\,A}$

$\therefore E_{bf.L} = V_a - I_{af.L} R_a = \boxed{205.6\,V}$

$\because E_b = \dfrac{\phi P . N Z}{60 A}$ $\therefore N \propto \dfrac{E_b}{\phi}$ $\therefore N = K \dfrac{E_b}{\phi}$

$\therefore \dfrac{N_1}{N_2} = \dfrac{(E_{b1})/(\phi_1)}{(E_{b2})/(\phi)_2}$ but ϕ is const. → shunt motor

$\therefore \dfrac{N_1}{N_2} = \dfrac{E_{b1}}{E_{b2}}$ $\therefore \dfrac{N_{n.L}}{N_{f.L}} = \dfrac{E_{bo}}{E_{bf.L}}$

$\therefore N_{f.L} = \dfrac{E_{bf.L}}{E_{bo}} \cdot N_{n.L}$

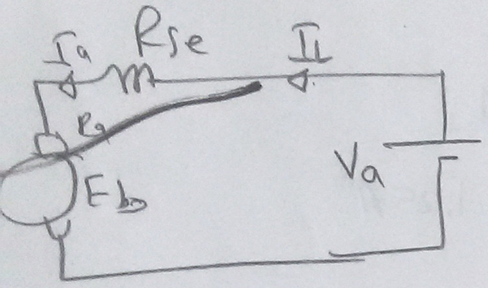
$\boxed{\therefore N_{f.L} = 939.67\,rpm}$ #

(5)

blem (3) series Motor $N_1 = 800\,rpm$, $I_{L_1} = 20\,A$

$I_{L2} = 50\,A$, $N_2 = ?$, $R_a = 0.2\,\Omega$, $R_{se} = 0.3\,\Omega$

$\varphi \propto I_a, I_L$, $V_a = 250\,V$



الحل

→ For Load (1) $N_1 = 800\,rpm$

$I_{a1} = I_{L1} = 20\,A$

$\because V_a = E_b + I_a(R_a + R_{se})$

$\therefore E_{b1} = V_a - \overset{20}{I_{a1}}(R_a + R_{se})$

$\therefore \boxed{E_{b1} = 240\,V}$

→ for Load (2) $I_{a2} = I_{L2} = 50\,A$ $\therefore E_{b2} = V_a - \overset{50}{I_{a2}}(R_a + R_{se})$

$\therefore N \propto \dfrac{E_b}{\varphi}$, $\varphi \propto I_a, I_L$ $\therefore \boxed{E_{b2} = 225}$

$\therefore \dfrac{N_1}{N_2} = \dfrac{(E_{b1}/I_{a1})}{(E_{b2}/I_{a2})}$ $\therefore \dfrac{N_1}{N_2} = \dfrac{E_{b1} \cdot I_{a2}}{E_{b2} \cdot I_{a1}}$

$\therefore N_2 = N_1 \cdot \dfrac{E_{b2} \cdot I_{a2}}{E_{b1} \cdot I_{a1}} = 800 \times \dfrac{225 \times 20}{240 \times 50}$

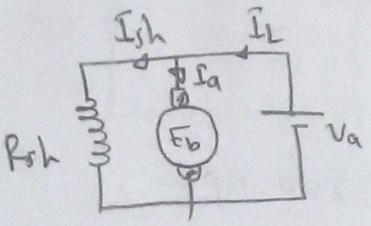
$\therefore \boxed{N_2 = 300\,rpm}$ #

(6)

problem ④ $V_a = 250V$ shunt, $R_{sh_1} = 200\Omega$, $R_a = 0.3\Omega$

$N_1 = 1500rpm$, $I_{L_1} = 22A$, $R_{sh_{new}} = 200 + 150\Omega$ → $I_{a_{new}} = ?$

$N_{2_{new}} = ?$ Assume load torque = const.



→ for the first load

$I_{L_1} = 22A = I_{a_1} + I_{sh_1}$

$I_{sh_1} = \frac{V_a}{R_{sh_1}} = \frac{250}{200} = 1.25A$

$\therefore \boxed{I_{a_1} = 20.75A}$ $\therefore E_{b_1} = V_a - I_{a_1} R_a$

$\therefore E_{b1} = 250 - 20.75 \times 0.3 = \boxed{243.775V}$

$\because T_a = 0.159 \, \phi I_a \cdot \frac{PZ}{A}$ $\therefore T_a \propto \phi I_a$, $\phi \propto I_{sh}$

$\therefore T_a \propto I_{sh} I_a$ $\therefore \frac{T_1}{T_2} = \frac{I_{sh_1} \cdot I_{a_1}}{I_{sh_2} \cdot I_{a_2}}$

$\because$ Said Load torque = Const → $\therefore T_1 = T_2$

$\therefore I_{sh_1} I_{a_1} = I_{sh_2} I_{a_2}$

$I_{sh_2} = \frac{V_a}{R_{sh_{new}}} = \frac{250}{200+150} = \boxed{0.7142A}$

$\therefore I_{a_2} = \frac{I_{sh_1} I_{a_1}}{I_{sh_2}} = \boxed{36.3125A}$

$\therefore E_{b2} = V_a - I_{a2} R_a$

$\therefore \boxed{E_{b2} = 239.1062V}$

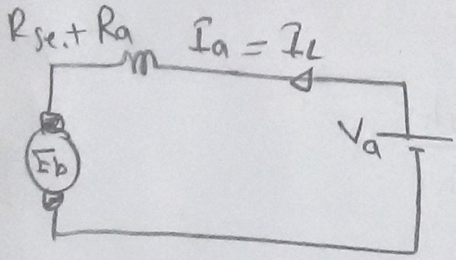
$\because N \propto \frac{E_b}{\phi}$ $\therefore \frac{N_1}{N_{2_{new}}} = \frac{E_{b1}}{E_{b2}} \cdot \frac{I_{sh2}}{I_{sh_1}}$

$\therefore \boxed{N_{2_{new}} = 2575.03 \, rpm}$ #

Problem (5) series at $N_1 = 500 rpm$, $V_a = 220V$, $I_{L_1} = 50A$

$(R_a + R_{se.}) = 0.15\,\Omega$, $R_{ext.} = ? \rightarrow N_2 = 300 rpm$

$T_{L_2} = \frac{1}{2} T_{L_1}$, $\phi \propto I_a, I_L$



الحل

$\because V_a = E_{b_1} + I_{a_1}(R_a + R_{se.})$

$I_{a_1} = I_{L_1} = 50A$

$\therefore E_b = 220 - 50(0.15) = \boxed{212.5V}$

$V_a = E_{b_2} + I_{a_2}(R_a + R_{se.} + R_{ext.})$

for Computing I_{a2}

$\because T \propto \phi I_a$, $\phi \propto I_a$ $\therefore T \propto I_a^2$

$\therefore \frac{T_1}{T_2} = \frac{I_{a1}^2}{I_{a2}^2} \rightarrow \frac{\cancel{T_1}}{\frac{1}{2}\cancel{T_1}} = \frac{(50^2)}{I_{a2}^2}$ $\therefore \boxed{I_{a2} = 35.355 A}$

$\therefore \underbrace{V_a}_{220} = E_{b2} + 35.355(0.15 + R_{ext.})$

for Computing E_{b2}

$\because N \propto \frac{E_b}{\phi}$ $\therefore \frac{N_1}{N_2} = \frac{E_{b1}}{E_{b2}} \cdot \frac{I_{a2}}{I_{a1}}$

$\therefore \frac{500}{300} = \frac{212.5 * 35.355}{E_{b2} * 50}$ $\therefore \boxed{E_{b2} = 90.0279V}$

$\therefore 220 = 90.0279 + 35.355(0.15 + R_{ext.})$

$\boxed{\therefore R_{ext.} = 3.526\,\Omega}$ #

(8)

problem (6) $V_a = 500V$ shunt $N_1 = 250$ rpm $\rightarrow I_{a1} = 200A$, $R_a = 0.12\Omega$

$N_2 = ?$ $I_{sh2} = 80\% \, I_{sh1} \rightarrow I_{a2} = 100A$

حل

$$\because \frac{N_1}{N_2} = \frac{E_{b1}}{E_{b2}} \cdot \frac{I_{sh2}}{I_{sh1}} \rightarrow \frac{0.8 \cancel{I_{sh1}}}{\cancel{I_{sh1}}}$$

$$E_{b1} = V_a - I_{a1} R_a = 500 - 200 * 0.12 = \boxed{476V}$$

$$E_{b2} = V_a - I_{a2} R_a = 500 - 100 * 0.12 = \boxed{488V}$$

$$\therefore \frac{250}{N_2} = \frac{476}{488} * 0.8 \quad \therefore \boxed{N_2 = 320.378 \text{ rpm}} \#$$
